



High-Rate Composites for Aircraft Manufacturing

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- **Motivation: Projected Transportation Needs**
- **High-Rate Composites Aircraft Manufacturing (HiCAM) Project Objectives and Approach**
- **Preliminary HiCAM Thermoplastic Automated Fiber Placement (TP-AFP) Results**

Composite Transport Market Demand and Opportunity



- The global aviation system of 2040 is emerging today – new companies and new systems built on advanced technologies, many with “NASA DNA” and enabled by steady U.S. industry investment.

Boeing & Airbus market outlook:

- By 2040, > 43,000 deliveries
 - replace 80% current & double fleet size
 - single-aisle, 2nd decade demand ~150 per month

Historic aircraft production rates per month:

- Metals (B737, A320) : 60 1.3x = 80
- Composites (B787, A220) : 10-14 6x = 80

Increased Emphasis on Sustainability:

- Reduced emissions (weight, drag)
- Reduced operating costs (fuel, acquisition, maintenance)

Market drivers: earlier deliveries (high production rate), cost reductions & performance improvements.

NASA High-rate Composites for Aircraft Manufacturing (HiCAM)



NASA, US Industry, and Universities have partnered in the Advanced Composites Consortium (ACC) to respond to these challenges and to deliver the desired outcomes with the following understanding:

Not plausible to scale current composites production system 6x:

- **Supply chain: limited skilled labor and specialized equipment; Difficult to ramp and adjust with demand**
- **Scaling current composites production doesn't reduce acquisition cost**
- **Technology needed to improve production efficiency (increasing rate, while reducing cost)**
- **Requires more efficient use of manufacturing factory footprint**

Continuing to advance aviation in 2040 and beyond ... requires new capabilities for rapid manufacturing:

- **Future production rates require improvements and streamlined relationships in aircraft design, materials, certification and manufacturing methodologies**
- **Design, certification and manufacturing are inseparable and must be considered together early in the aircraft conceptualization process**
-

NASA HiCAM Project : Composites Manufacturing Focus Areas



Based on a NASA and industry workshop on advanced manufacturing¹ held in 2018 and subsequent discussions with the FAA and the ACC partners to assess the state of the art of rapid/advanced manufacturing, the following industry technology needs and proposed NASA investments were identified:

- Non-Destructive Inspection (NDI)
- Rapid Cure Infusion Resins
- Stitched Resin Infusion
- Thermoplastic Forming
- Thermoplastic Assembly
- **Thermoplastic Automated Fiber Placement (TP-AFP)**
- Next Generation (Rapid) Thermoset AFP and Cure
- Validated Process Model Software Tools
- Validated Progressive Damage Analysis (PDA) Model Software Tools
- Design For Manufacturing (DFM) Software Tools

Topic of Technical
Presentation
today

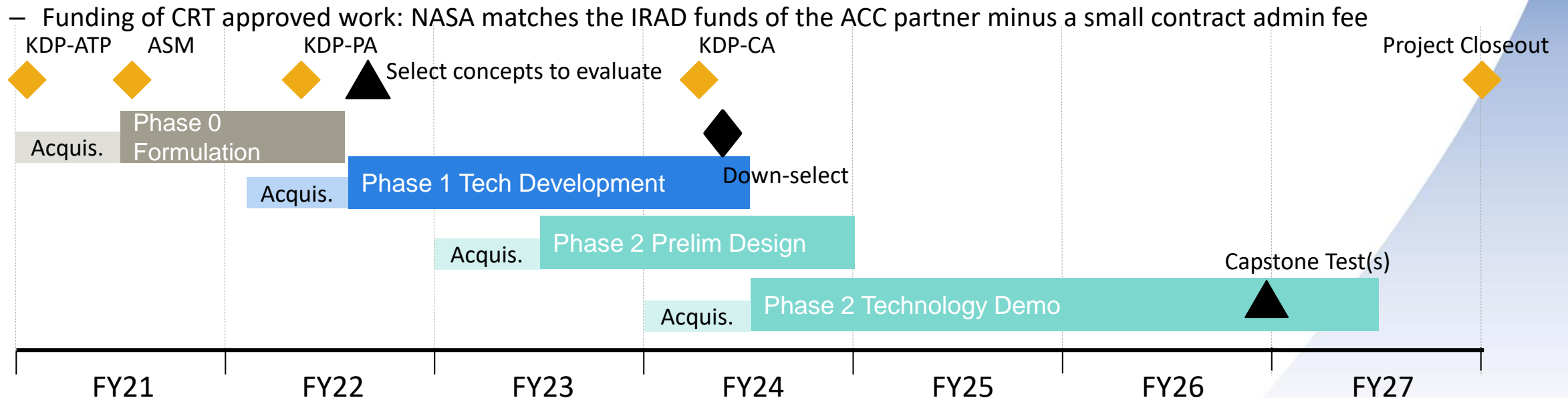


In addition to the technology insertion points listed , NASA, Boeing and Spirit are conducting trade studies with a baseline design in to identify the technologies to develop to reach the 6X goal of composite wing and fuselage ship-sets per month.

HiCAM and the Advanced Composites Consortium



- **Membership of ACC established based upon qualifications and selection criterion**
- To develop/award collaborative tasks performed by NASA and members of the ACC:
 - Project Technology Development Areas (Topics) identified with ACC partner input and listed on previous slide
 - Project issues request for proposals (RFPs) for specific Topics; NASA & partners form Cooperative Research Teams (CRTs), propose Project Work Plans (PWP)
 - PWPs reviewed/approved by ACC managing committees; NASA-only detailed cost and technical review
- HiCAM Project Manager- NASA LaRC Dr. Rick Young decides which PWPs to fund; NASA issues cooperative agreement contracts to partners



Current ACC partners in HiCAM Project



- **NASA**
- **ATC Manufacturing**
- **Boeing**
- **CGTech**
- **Collier Research**
- **Electroimpact**
- **GE Aviation**
- **Hexcel**
- **Northrup (NGSC)**
- **Rohr (Collins/RTX)**
- **Solvay**
- **SPIRIT**
- **Toray**
- **University of South Carolina (McNair)**
- **Wichita State University (NIAR)**

HiCAM Requirements, Performance Metrics and Success Criteria



Requirements:

1. Airframe components shall comply with Airworthiness Standards required for aircraft certification
2. Maturity: technology readiness level (TRL) and manufacturing readiness level (MRL)
 - a) Manufacturing technologies matured to TRL 6, MRL 6 by Project Closeout
 - b) Related Model based engineering (MBE) tools matured to TRL 6 by Project Closeout

Performance Metrics:

KPP

Composite Production Rate

HiCAM Full Success

80 Shipsets per Month

HiCAM Min Success

60 Shipsets per Month

Component Net Cost per Shipset

Cost Reduction > 50% of Baseline

Cost Reduction > 30% of Baseline

Component Weight

>2% lighter than baseline

<2% Heavier than Baseline

MBE Tool Accuracy

Predicts Experimental Values within
Stakeholder-defined Tolerance

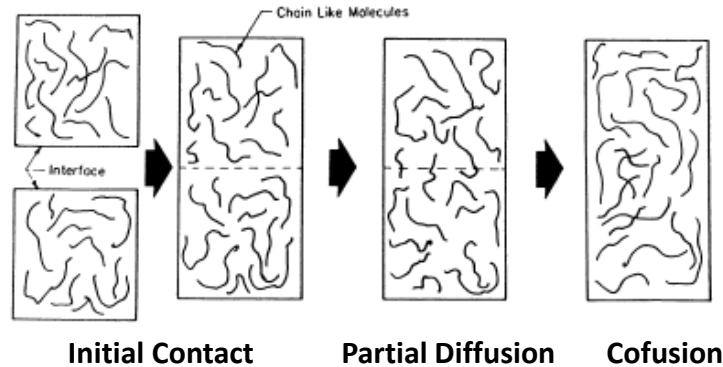
Simulates Experimental Trends

Capstone demonstration will anchor and validate technology models that show ~80 aircraft a month is achievable with cost and weight reductions.

Thermoplastic Composites Automated Fiber Placement



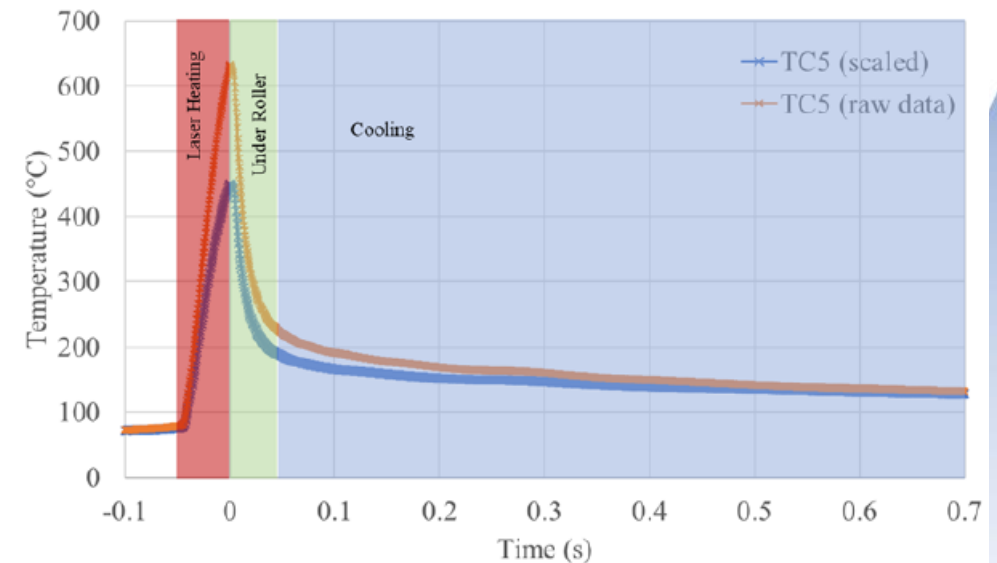
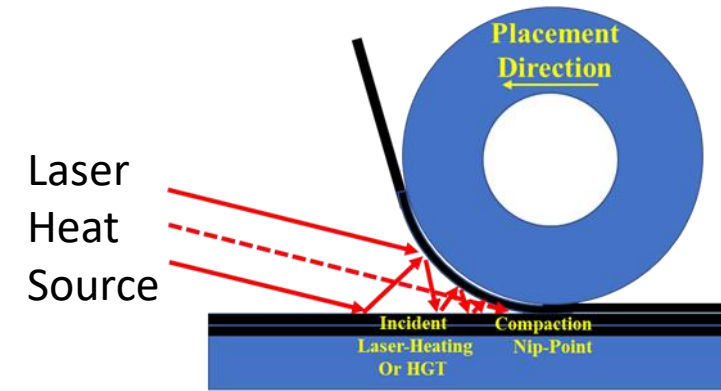
- Thermoplastic matrix composites have high potential in rapid manufacturing because of inherently low process cycle times



Thermoplastic Fusion-Bonding (Autohesion) Phenomenon²

CF/Thermoplastic tape plies consolidate into a laminate by fusion bonding at the interfaces.

- The interfacial bond strength is a function of the processing temperature, contact pressure, and contact time.
- Interfacial bond strength increases with time due to interdiffusion of mobile molecular chain ends across the interface.
- After intimate contact, interpenetration and re-entanglement of the polymer chains occurs and ultimate cohesive strength is achieved.

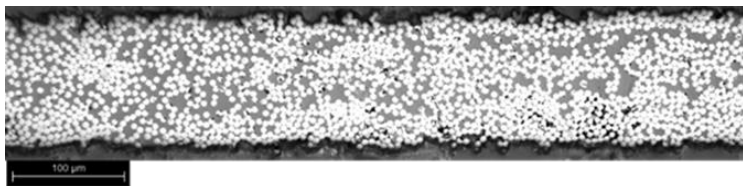


²Reference: A.C. Loos and P.H. Dora: "PROCESSING OF THERMOPLASTIC MATRIX COMPOSITES." NASA/Contractor Report–NASA Grant NAG1-343; DOI: 10.1007/978-1-4613-1893-4_143

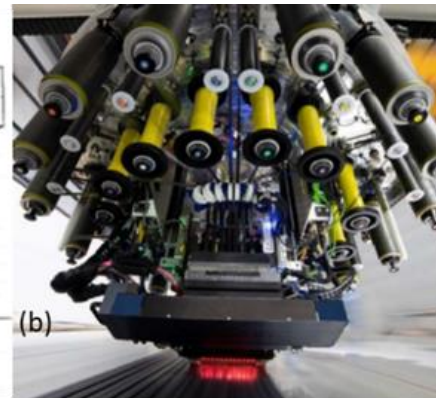
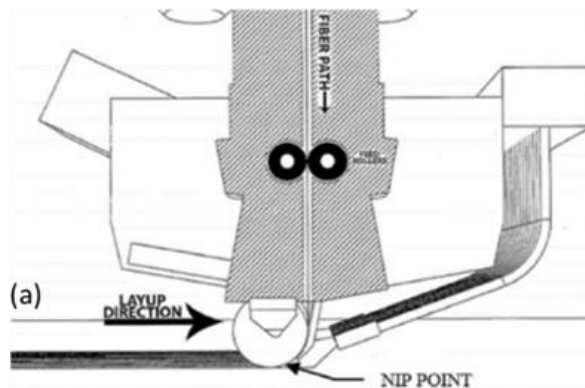
NASA ICAT Processing Trials with Electroimpact, Inc.



- During this first year of the HiCAM project NASA has partnered with SPIRIT, Raytheon, Electroimpact, and NIAR on the quantitative assessment of In-situ Consolidation AFP of Thermoplastics (ICAT), which is TP-AFP without any oven or autoclave post-consolidation steps; In ICAT: Intimate contact, autohesion and crystallization all occur during the placement process on heated tooling.
- NASA and Electroimpact ICAT Process Assessment:



Toray TC1200 T800/PEEK;
145gsm, 34% RC slit tape; $T_M=343^{\circ}\text{C}$



Electroimpact VSS-HP Laser system concept (a) and Image of EI 16-tow head (b) placing 0.25" tapes [8] during ICAT trials ³



Victrex LM-PAEK IM7/AE250;
148gsm, 34% RC slit tape; $T_M=309^{\circ}\text{C}$

Results of NASA ICAT DoE: Toray TC1200 PEEK



ICAT processing DoE at Electroimpact varying Laser Target Temperature (LT), Tool Temperature (TT) and Placement Speed (V) for two 0.25" slit-tape materials:



LT=400°C, TT=80°C, V= 170 mm/sec (402 in/min)*



LT=450°C, TT=120°C, V= 250 mm/sec



LT=500C, TT=120C, V= 400 mm/sec (945 in/min)



LT=400°C, TT=120°C, V= 250 mm/sec (591 in/min)



LT=500C, TT=80C, V= 250 mm/sec



LT=500C, TT=120C, V= 100mm/sec (236 in/min)

Poor Contact
(red arrows)

Process Recipe Selected
for SBS test panel

Results of NASA ICAT DoE: Victrex IM7/AE250 LM-PAEK



LT=350°C, TT=80°C, V= 170 mm/sec (402 in/min)

Poor Contact
(red arrow)



LT=450°C, TT=120°C, V= 250 mm/sec



LT=400°C, TT=120°C, V= 250 mm/sec (591 in/min)



LT=450°C, TT=80°C, V= 250mm/sec

Process Recipe Selected
for SBS test panel

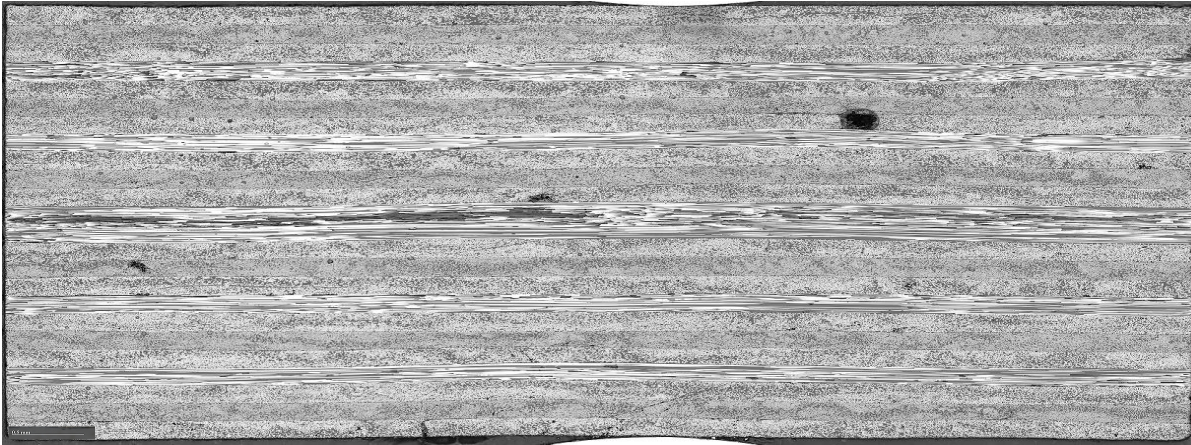


LT=450°C, TT=80°C, V= 400mm/sec (945 in/min)

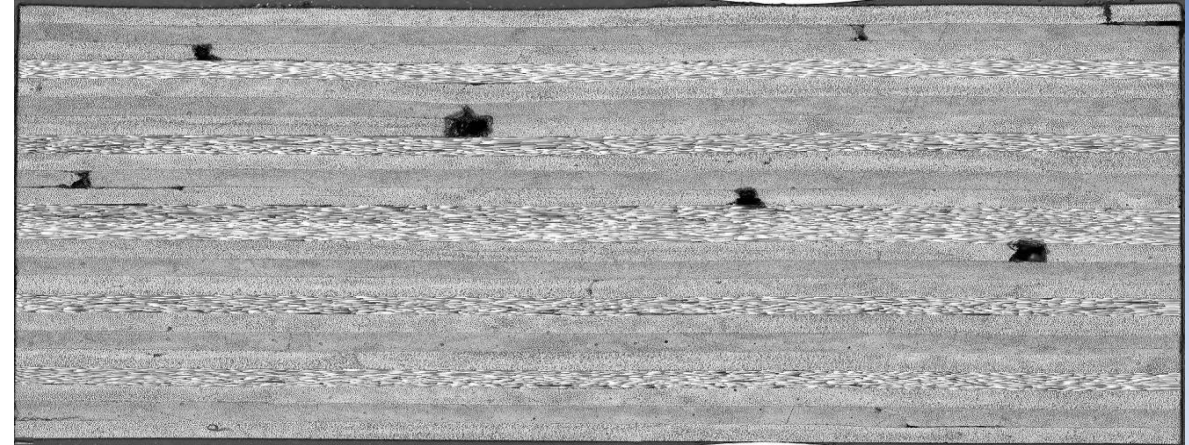
ICAT SBS Test Panels



- Using the ICAT process parameters identified in the abbreviated DoE, one PEEK panel and one LM-PAEK panel were fabricated with quasi lay-up: $[45^\circ / 0^\circ / -45^\circ / 90^\circ]_{35}$. After ICAT processing the resulting panels were cut into three sections using a wet-saw resulting in:
 - PEEK and LM-PAEK ICAT panels
 - PEEK and LM-PAEK ICAT + Vacuum-Bag Oven (VBO) post consolidation panel
 - PEEK and LM-PAEK ICAT + Autoclave post-consolidation panel
- ASTM D2344 testing is in progress of the SBS coupons from these panels.



ICAT Fabricated PEEK Panel



ICAT Fabricated LM-PAEK Panel



- The new Variable Spot Size, High Power (VSS-HP) laser heating system developed by Electroimpact is capable of heating the surfaces of the PEEK and PAEK tapes to the target temperatures of up to 500°C at speeds up to 400mm/sec (945in/min)
- Based on photo-microscopy of the panels fabricated, it appears that intimate contact was established for the CF/ Poly(aryletherketone) thermoplastic materials during ICAT:
- PEEK tape at LT=500°C, TT= 120°C, and V=100 mm/sec
- LM-PAEK tape at LT=450°C, TT=80°C, and V= 400 mm/sec
- The degree of fusion-bonding (consolidation) at these processing conditions will be determined by SBS testing... currently in progress



Questions?